

# B Physics at CDF and DØ



Wendy Taylor



for the CDF and  
DØ Collaborations

Aspen 2005 Winter  
Conference

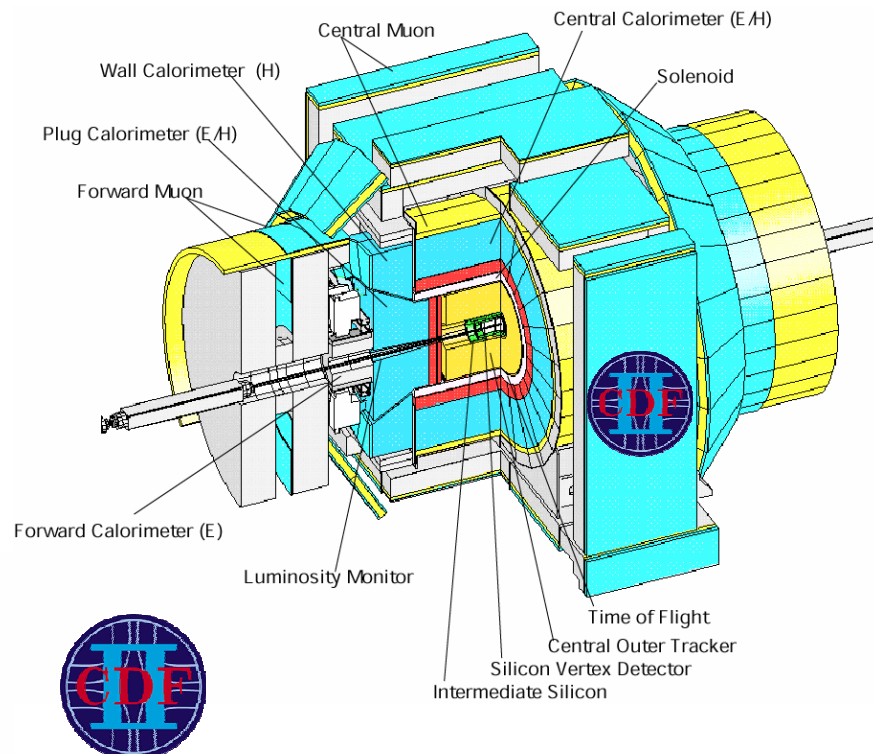
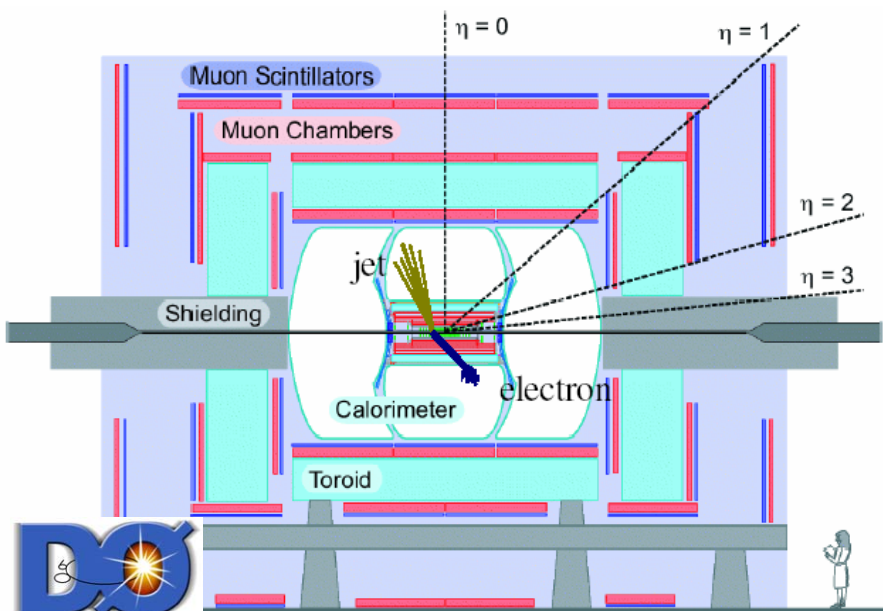
February 18, 2005

# Detectors



- Excellent muon and tracking coverage  $\Rightarrow$  high yields

- ◆ Extended muon system  $|\eta| < 2.0$
- ◆ Tracking up to  $|\eta| < 3.0$



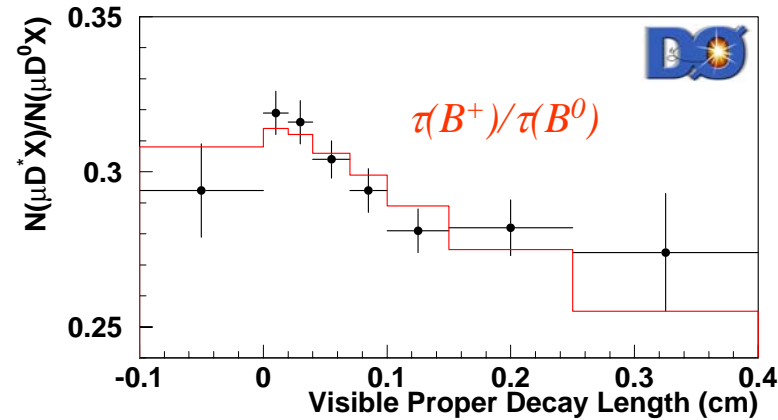
- Excellent mass resolution
- Particle ID:  $p$ ,  $K$  and  $\pi$  by  $dE/dx$  and TOF
- Hadronic trigger able to trigger on two-track objects at L1
- Impact parameter trigger at L2





# Lifetime Measurements



- Precision measurements constrain inputs to theoretical calculations utilizing non-perturbative techniques
- Theoretical and experimental uncertainties are reduced for ratios of lifetimes



Measurement	Channel	PDG	 CDF Result	 DØ Result
$\tau(B^+)/\tau(B^0)$	$B^+ \rightarrow J/\psi K^+$ $B^0 \rightarrow J/\psi K^{*0}$	$1.086 \pm 0.017$	$1.080 \pm 0.042$	
$\tau(B^+)/\tau(B^0)$	$B \rightarrow D^*(2010)^- \mu^+ X$ $B \rightarrow \bar{D}^0 \mu^+ X$	$1.086 \pm 0.017$		$1.080 \pm 0.016 \pm 0.014$
$\tau(B_s)$	$B_s^0 \rightarrow J/\psi \phi$	$1.461 \pm 0.057 \text{ ps}$	$1.369 \pm 0.100^{+0.008}_{-0.010} \text{ ps}$	$1.444^{+0.098}_{-0.090} \pm 0.020 \text{ ps}$
$\tau(\Lambda_b)$	$\Lambda_b^0 \rightarrow J/\psi \Lambda^0$	$1.229 \pm 0.080 \text{ ps}$	$1.25 \pm 0.26 \pm 0.10 \text{ ps}$	$1.22^{+0.22}_{-0.18} \pm 0.04 \text{ ps}$



# $B_c$ Mass and Lifetime at DØ

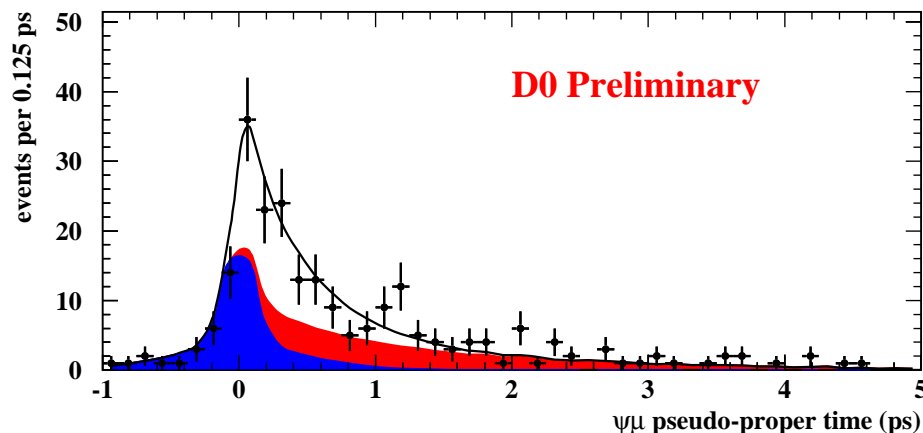
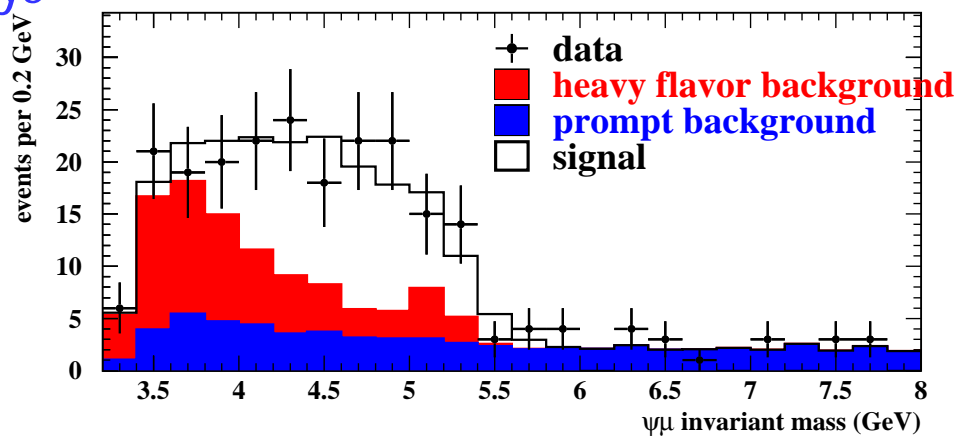
- Trigger on  $J/\psi \rightarrow \mu^+ \mu^-$  decays in 210 pb<sup>-1</sup> of DØ data
- Reconstruct  $B_c^+ \rightarrow J/\psi \mu^+ X$  decays

- 231 candidates, signal of  $95 \pm 12 \pm 11$  events
- Unbinned likelihood fit gives

$$m = 5.95 \pm 0.14 \pm 0.34 \text{ GeV}/c^2$$

- Average correction factor determined from Monte Carlo to account for the missing momentum of the neutrino gives

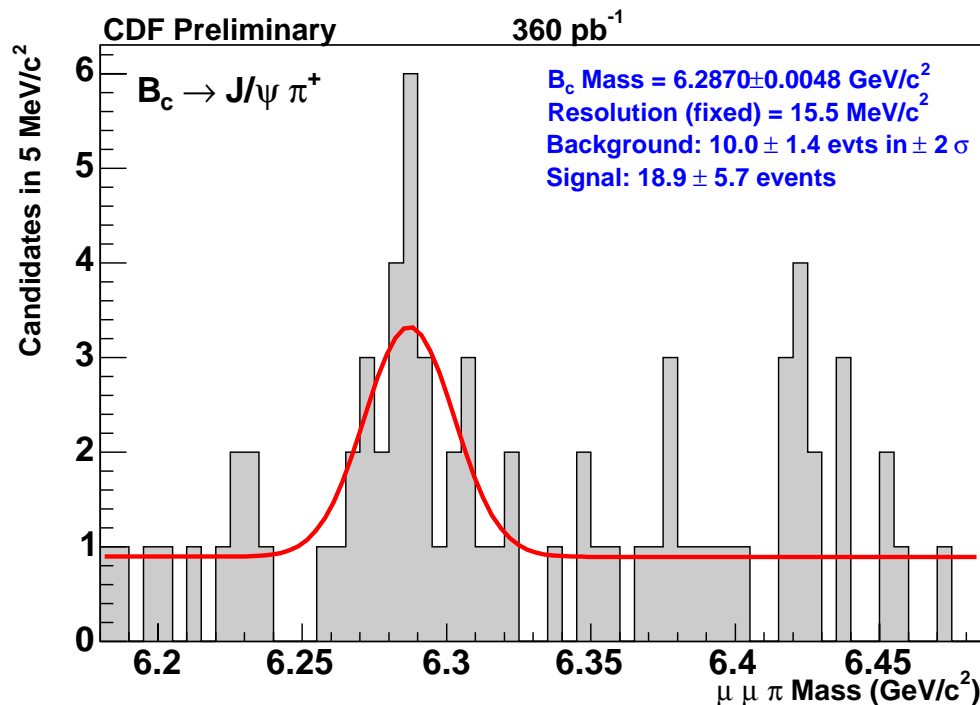
$$\tau = 0.448^{+0.123}_{-0.096} \pm 0.121 \text{ ps}$$





# $B_c$ Mass at CDF

- Reconstruct  $B_c^\pm \rightarrow J/\psi \pi^\pm$  decays 360 pb<sup>-1</sup> of CDF data
- Layer 00 used for this analysis
- Expected signal rate is order of magnitude smaller than the semileptonic mode
- **19** signal event over a background of **10** events expected yields

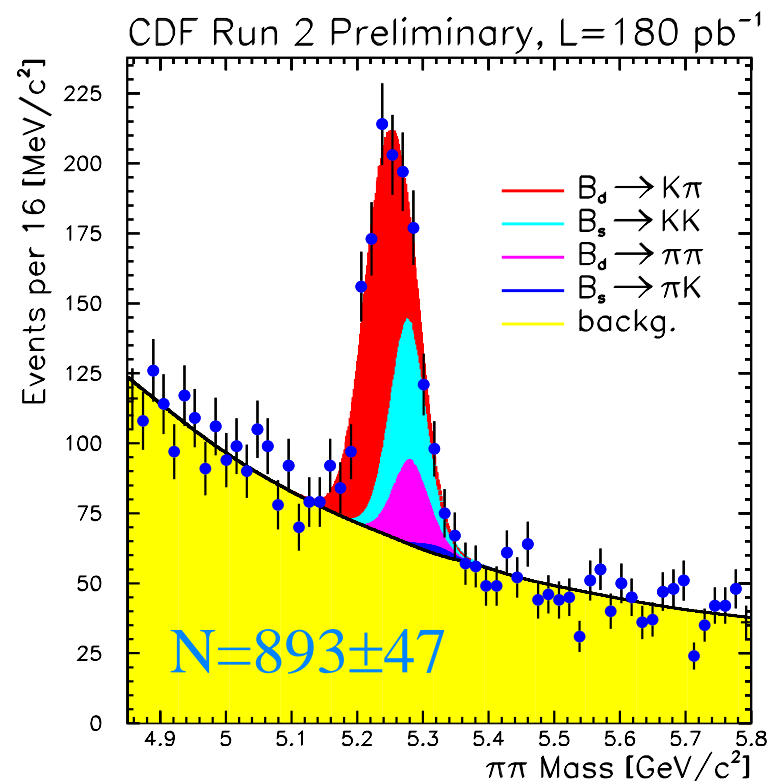
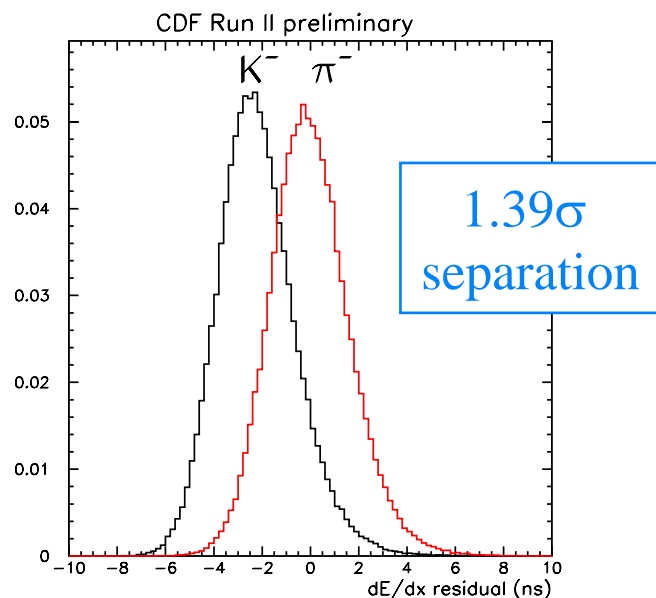


$$m = 6.2870 \pm 0.0048 \pm 0.0011 \text{ GeV}/c^2$$



# Charmless B Decays $B \rightarrow hh$ at CDF

- Charmless 2-body  $B$  decays  $B \rightarrow h^+ h'^-$ ,  $h, h' = K, \pi$  collected by hadronic  $B$  trigger
  - selects track pairs that exit a displaced vertex
- Use  $dE/dx$  in drift chamber to separate pions and kaons





# $B \rightarrow hh$ Branching Fractions at CDF

$$\frac{BR(B_d \rightarrow \pi^\pm \pi^\mp)}{BR(B_d \rightarrow K^\pm \pi^\mp)} = 0.24 \pm 0.06(stat) \pm 0.05(syst)$$

**First Measurement**

$$\frac{f_s \cdot BR(B_s \rightarrow K^\pm K^\mp)}{f_d \cdot BR(B_d \rightarrow K^\pm \pi^\mp)} = 0.50 \pm 0.08(stat) \pm 0.07(syst)$$

$$\frac{f_d \cdot BR(B_d \rightarrow \pi^\pm \pi^\mp)}{f_s \cdot BR(B_s \rightarrow K^\pm K^\mp)} = 0.48 \pm 0.12(stat) \pm 0.07(syst)$$

$$\frac{BR(B_s \rightarrow \pi^\pm \pi^\mp)}{BR(B_s \rightarrow K^\pm K^\mp)} < 0.10 @ 90\% C.L.$$

$$\frac{BR(B_d \rightarrow K^\pm K^\mp)}{BR(B_d \rightarrow K^\pm \pi^\mp)} < 0.17 @ 90\% C.L.$$

$$\frac{f_s \cdot BR(B_s \rightarrow K^\pm \pi^\mp)}{f_d \cdot BR(B_d \rightarrow K^\pm \pi^\mp)} = 0.11 @ 90\% C.L.$$



# CP Violation in Charmless Two-Body B Decays $B \rightarrow hh$ at CDF

- Direct CP asymmetry

$$A_{CP} = \frac{N(\bar{B}_d^0 \rightarrow K^- \pi^+) - N(B_d^0 \rightarrow K^+ \pi^-)}{N(\bar{B}_d^0 \rightarrow K^- \pi^+) + N(B_d^0 \rightarrow K^+ \pi^-)}$$
$$= -0.04 \pm 0.08(stat) \pm 0.01(syst)$$



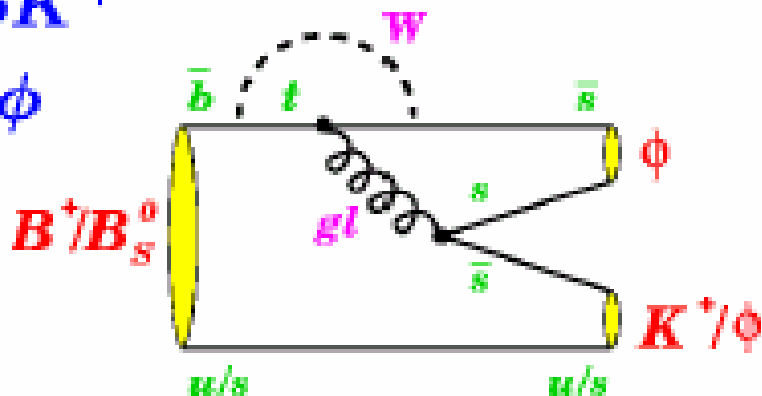


# Charmless B Decays $B_{d,s} \rightarrow \phi X$ at CDF

- Gluonic penguin-dominated decay followed by  $\phi \rightarrow K^+ K^-$

$$B^+ \rightarrow \phi K^+$$

$$B_s^0 \rightarrow \phi \phi$$

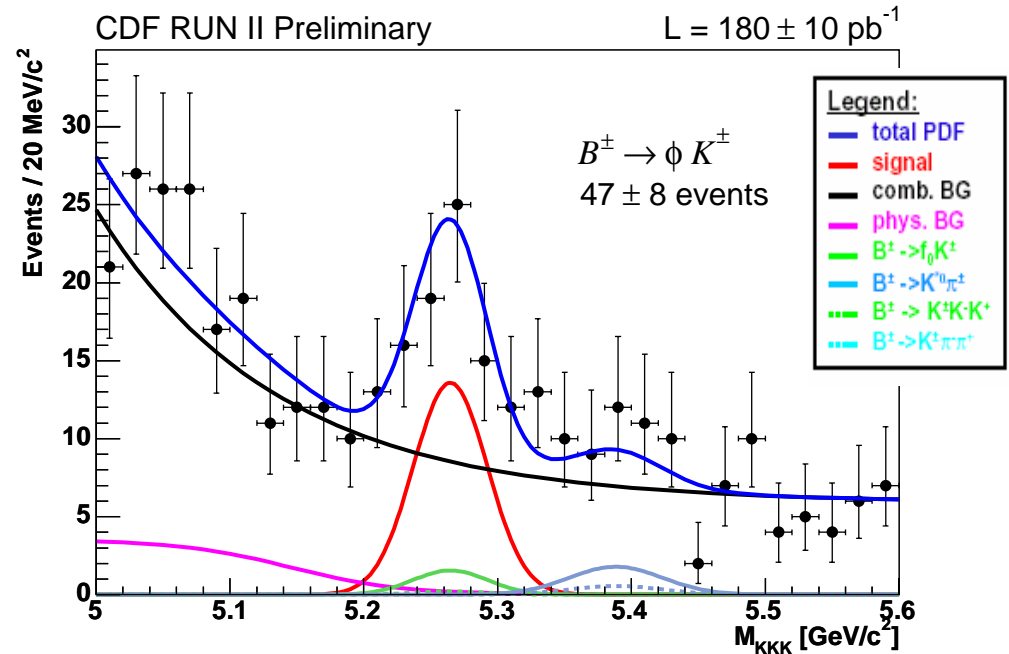


- Many beyond-the-SM theories predict new CP-violating phases resulting from heavy particles in the penguin loops



# Charmless B Decay $B^\pm \rightarrow \phi K^\pm$ at CDF

- Branching ratio measured relative to  $B^\pm \rightarrow J/\psi K^\pm$  (some uncertainties cancel)



$$BR(B^\pm \rightarrow \phi K^\pm) = (7.2 \pm 1.3(stat) \pm 0.7(syst)) \times 10^{-6}$$

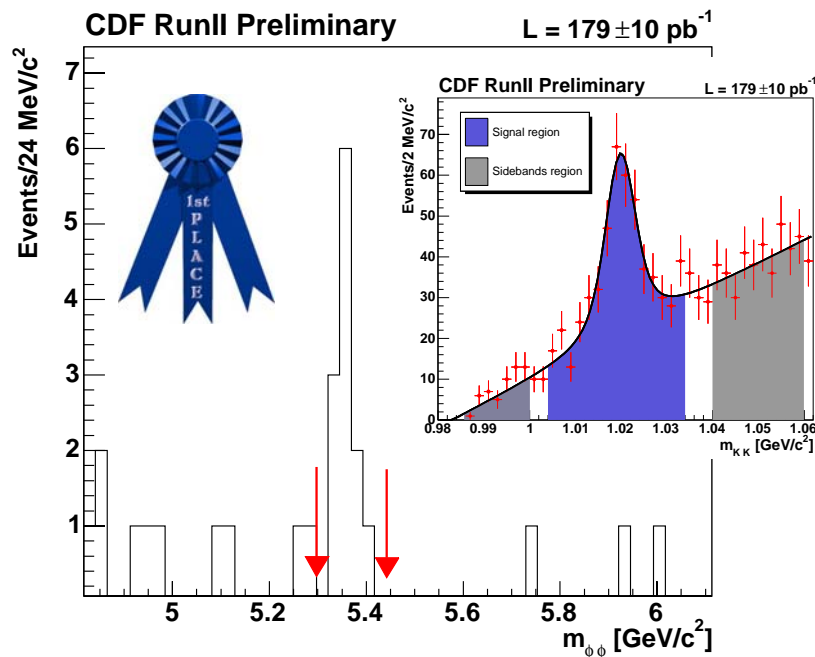
- HF averaging group  $\Rightarrow BR = (9.0 \pm 0.6) \times 10^{-6}$

$$A_{CP} = \frac{\Gamma(B^- \rightarrow \phi K^-) - \Gamma(B^+ \rightarrow \phi K^+)}{\Gamma(B^- \rightarrow \phi K^-) + \Gamma(B^+ \rightarrow \phi K^+)} = -0.07 \pm 0.17(stat) \pm 0.06(syst)$$



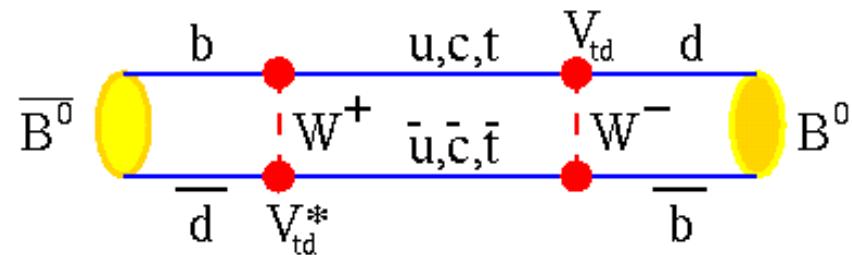
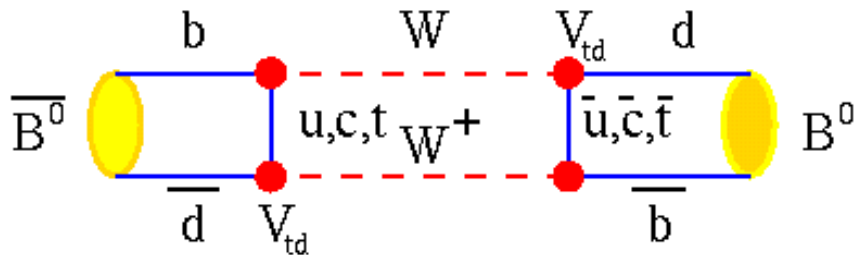
# Observation of $B_s \rightarrow \varphi \varphi$ at CDF

- Use  $B_s \rightarrow J/\psi \varphi$  as a normalization mode to avoid uncertainties due to the  $B_d$  and  $B_s$  fragmentation fractions
- 12 events in signal region, 2 background events expected
  - ◆ Combinatorics and reflections from  $B_d \rightarrow \varphi K^{*0}$
- $4.8\sigma$  signal
- First evidence for this decay mode
- $BR(B_s^0 \rightarrow \varphi \varphi) = (1.4 \pm 0.6(stat) \pm 0.2(syst) \pm 0.5(BR)) \times 10^{-5}$ 
  - ◆ SM predicts  $BR(B_s^0 \rightarrow \varphi \varphi) = (2.5 - 5.0) \times 10^{-5}$



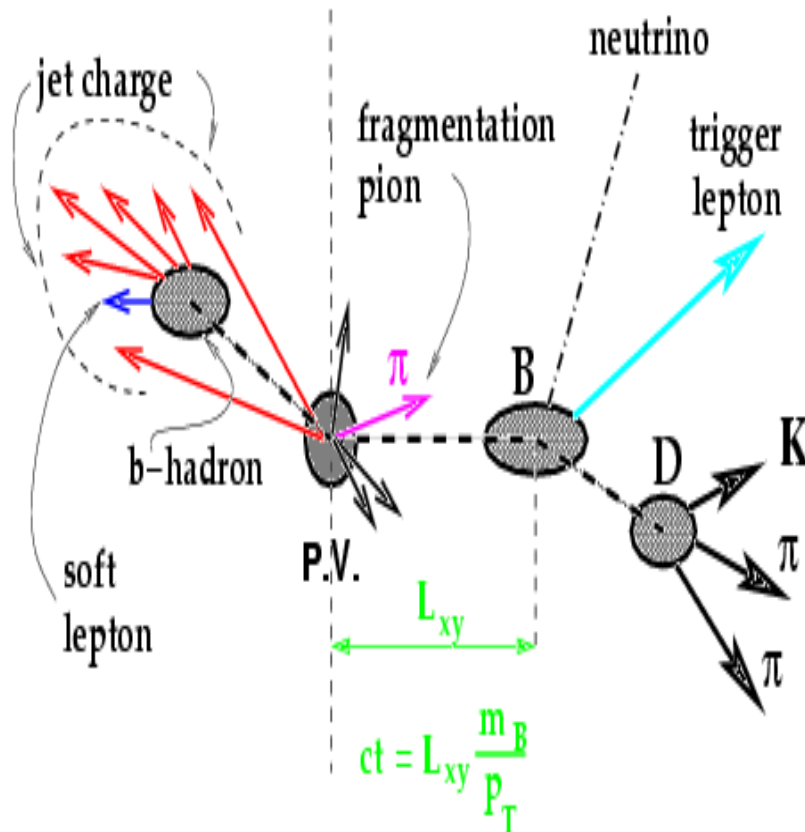
# $B_{d,s}$ Mixing

- $B_{d,s}$  mass and flavour eigenstates differ, allowing flavour states to mix



- ◆ Eigenstates have mass difference  $\Delta m_q = m_H - m_L > 0$
  - ◆ Eigenstates have width (lifetime) difference  $\Delta \Gamma_q = \Gamma_L - \Gamma_H > 0$
- Want to measure  $\frac{\Delta m_s}{\Delta m_d} = \frac{M(B_s)}{M(B_d)} \cdot \frac{\hat{B}(B_s) f^2(B_s)}{\hat{B}(B_d) f^2(B_d)} \cdot \left( \frac{V_{ts}}{V_{td}} \right)^2$
- Extract mass difference  $\Delta m_q$  from oscillation frequency

# $B_d$ Mixing



- Need to tag the production flavour of the  $b$  quark to know if meson mixed or not
  - ◆ Soft muon tagging
    - Low efficiency but high accuracy (*dilution*)
  - ◆ Jet-charge tagging
    - High efficiency but poor dilution
  - ◆ Same-side pion tagging
    - High efficiency but poor dilution

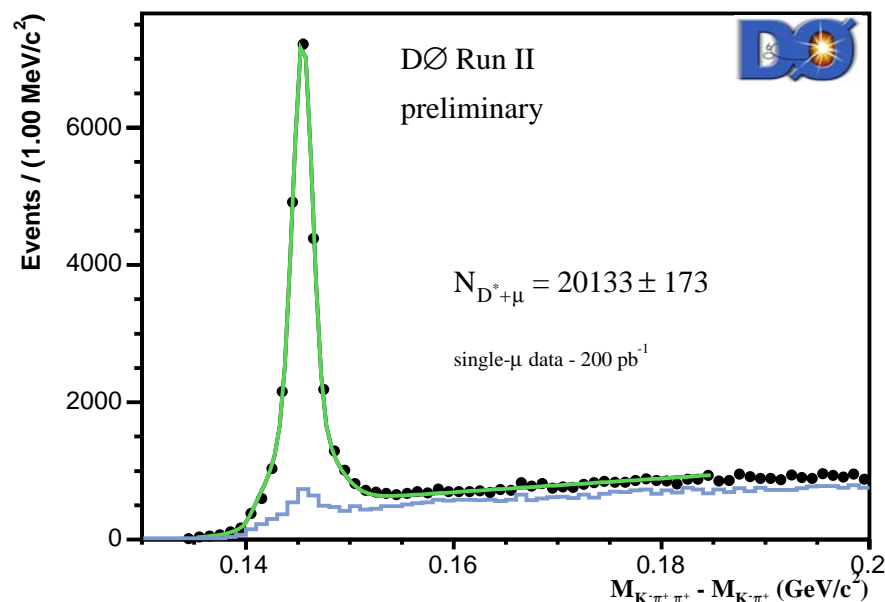


# $B_d$ Mixing at DØ

- Reconstruct  $B_d^0 \rightarrow D^{*(2010)-} \mu^+ X$  decays in 200 pb<sup>-1</sup> of DØ data
- Use  $B_d^0 \rightarrow \bar{D}^0 \mu^+ X$  decays for tagging studies
- Divide the data into 2 samples
  - ◆ Events that can be tagged by the soft muon tagger
  - ◆ The remaining events, which are subjected to the combined jet-charge and same-side tagger
    - Events with conflicting initial state flavour are rejected

- CDF used  $B \rightarrow D^{(*)} l^+ X$  decays in 245 pb<sup>-1</sup> of CDF data

$$B_d^0 \rightarrow D^{*(2010)-} \mu^+ X$$
$$\quad \quad \quad \hookrightarrow \bar{D}^0 \pi^-$$

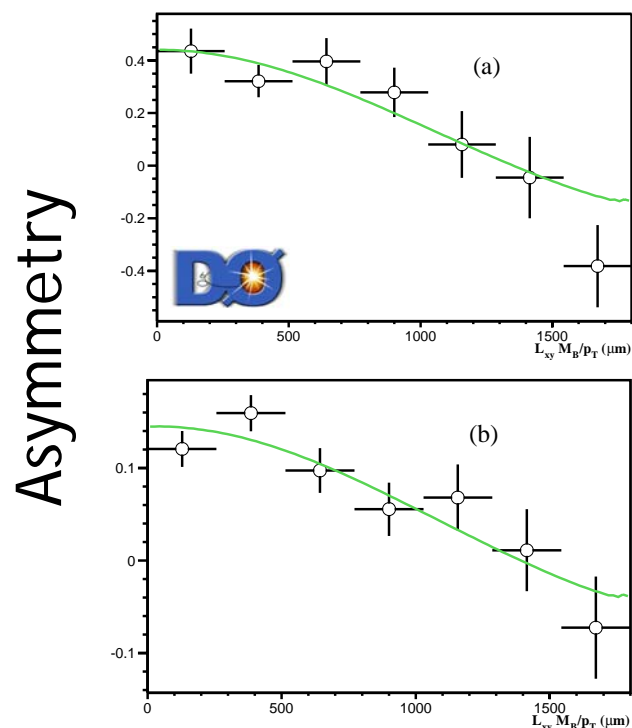




# $B_d$ Mixing

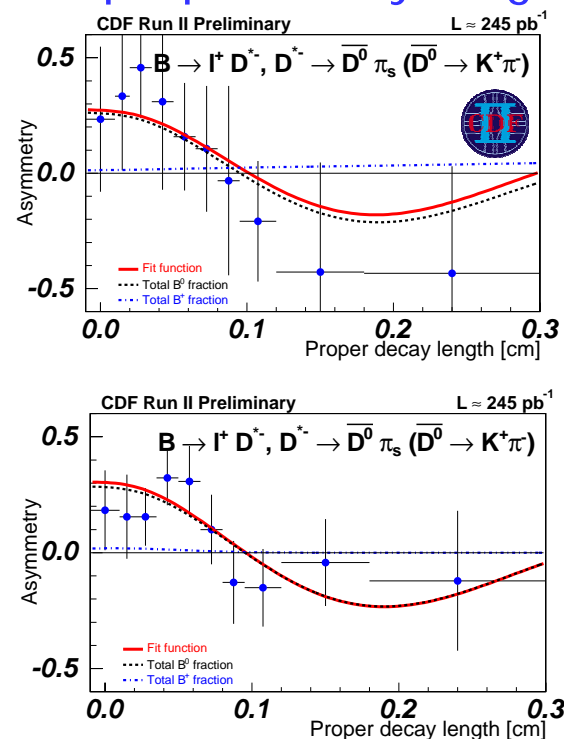


- Count the number of mixed and unmixed events in each decay length bin and plot asymmetry vs transverse pseudo-proper decay length



Soft muon tagger

Combined same-side  
and jet-charge tagger



DØ  $\Delta m_d$  Result

$$0.456 \pm 0.034 \pm 0.025 \text{ ps}^{-1}$$

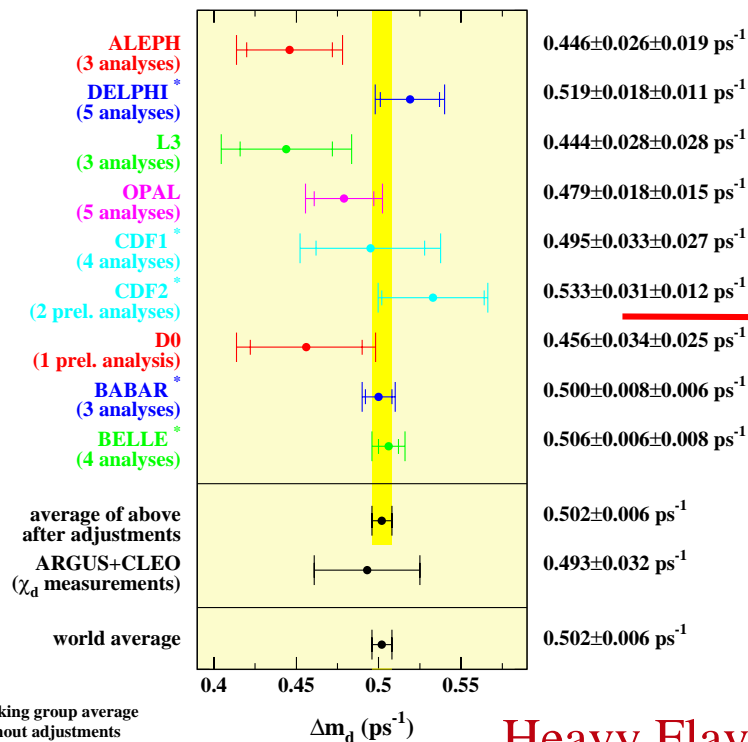
CDF  $\Delta m_d$  Result

$$0.536 \pm 0.037 \pm 0.015 \\ \pm 0.009(sc) \text{ ps}^{-1}$$

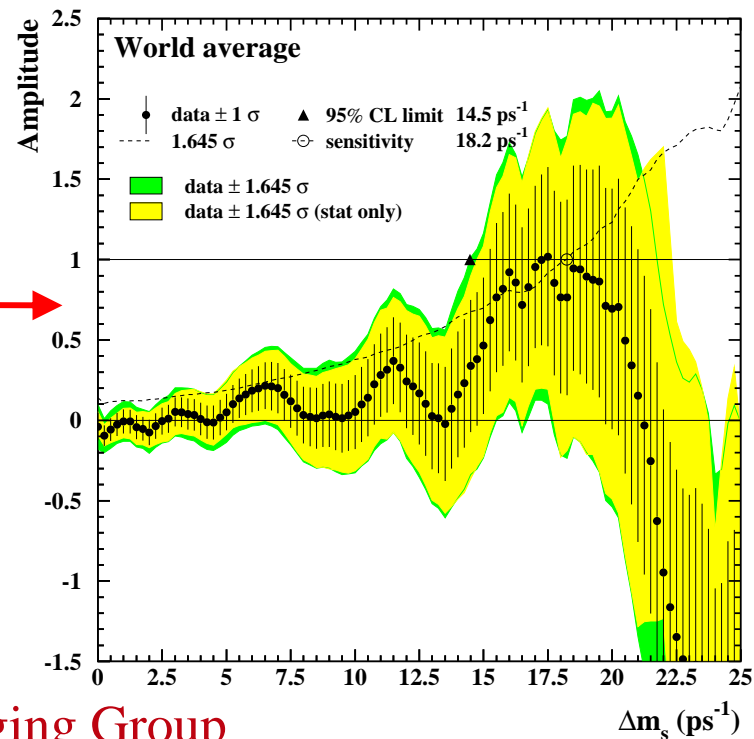
PDG  $\Delta m_d$

$$0.502 \pm 0.007 \text{ ps}^{-1}$$

# $B_d$ Mixing $\rightarrow B_s$ Mixing



Heavy Flavour Averaging Group



- Current 95% C.L. limit on  $\Delta m_s$ :  $14.4 \text{ ps}^{-1}$
- Standard Model says  $14.2 < \Delta m_s < 28.1 \text{ ps}^{-1}$  at 95% C.L.





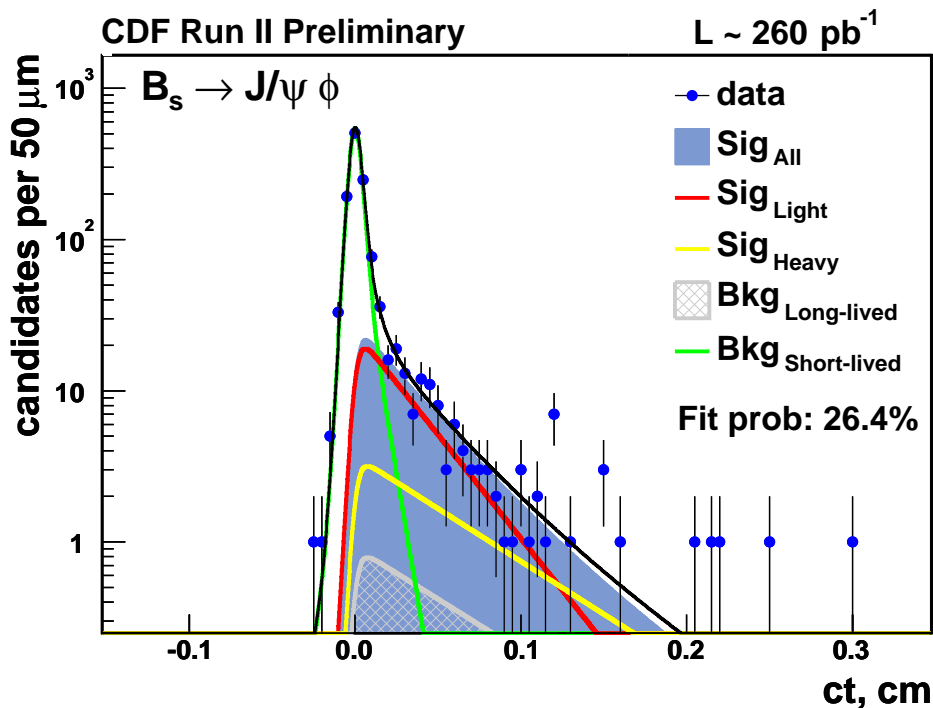
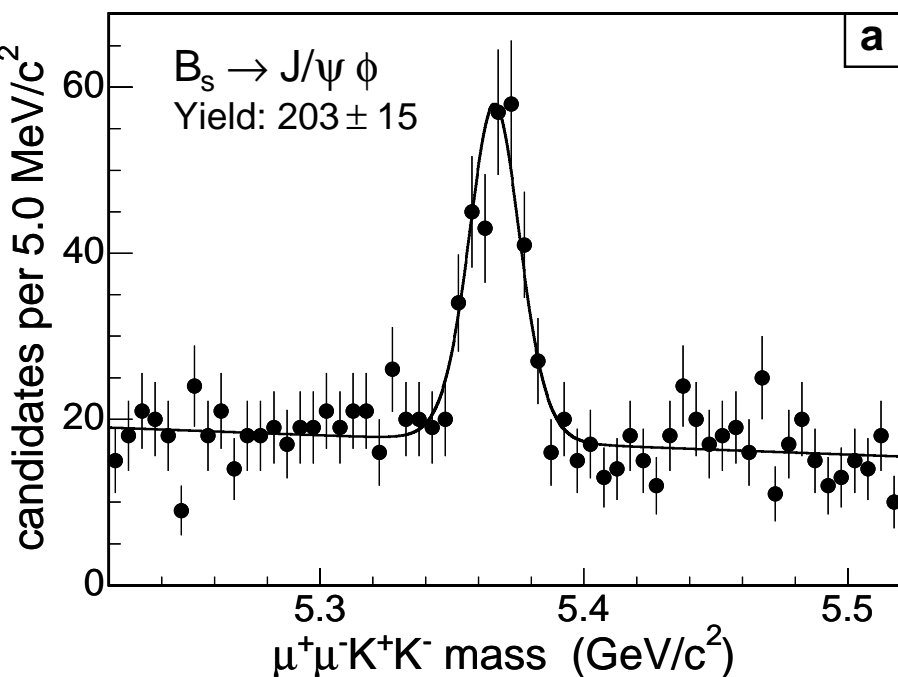
## $\Delta\Gamma(B_s)$ at CDF

- $\Delta\Gamma_d/\Gamma_d$  expected to be very small but  $\Delta\Gamma_s/\Gamma_s$  could be sizeable
- Mass eigenstates are expected to be nearly-CP eigenstates
- Light-mass eigenstate expected to be CP-even with larger decay width than heavier mass eigenstate
- Measure decay widths directly from the relative contributions of CP-even and CP-odd decays to the observed angular distributions as a function of decay time



# $\Delta\Gamma(B_s)$ at CDF

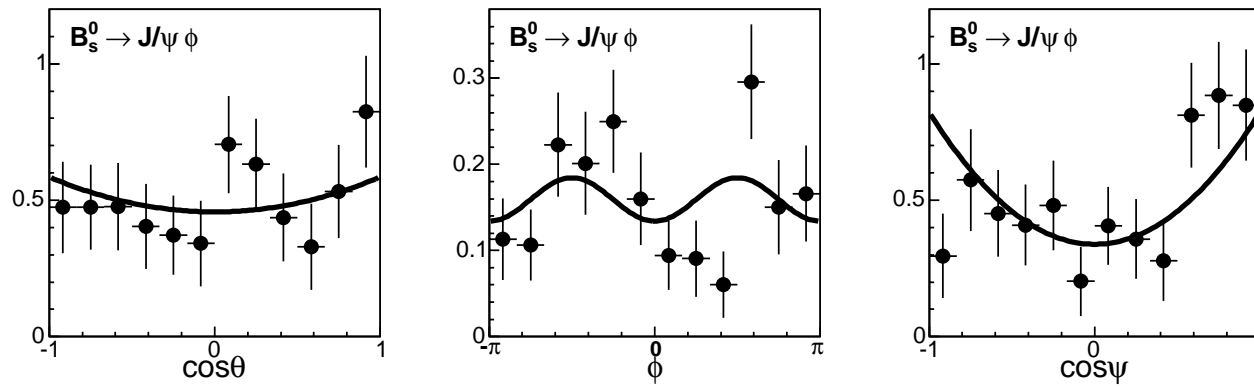
- Reconstruct  $B_s^0 \rightarrow J/\psi \phi$  followed by  $J/\psi \rightarrow \mu^+ \mu^-$  and  $\phi \rightarrow K^+ K^-$  in 260 pb<sup>-1</sup> of CDF data





# $\Delta\Gamma(B_s)$ at CDF

- Plot the “transversity” angular distributions for the mass-sideband-subtracted signal events
- First time-dependent angular analysis of  $B_s^0 \rightarrow J/\psi \phi$  decays



- Unbinned likelihood fit to mass, proper decay length and transversity angles to get

$$\Delta\Gamma_s = (0.47^{+0.19}_{-0.24} \pm 0.01) ps^{-1} \quad \frac{\Delta\Gamma_s}{\Gamma_s} = (65^{+25}_{-33} \pm 1)\%$$

- SM expectation:  $\frac{\Delta\Gamma_s}{\Gamma_s} = (12 \pm 5)\%$

# Rare Decays: $B_{d,s} \rightarrow \mu^+ \mu^-$

- Flavour-Changing Neutral Current process forbidden at tree level in the SM

- SM expectation:

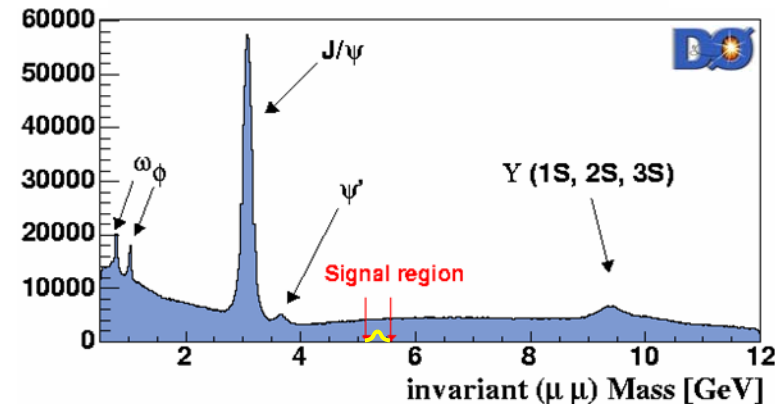
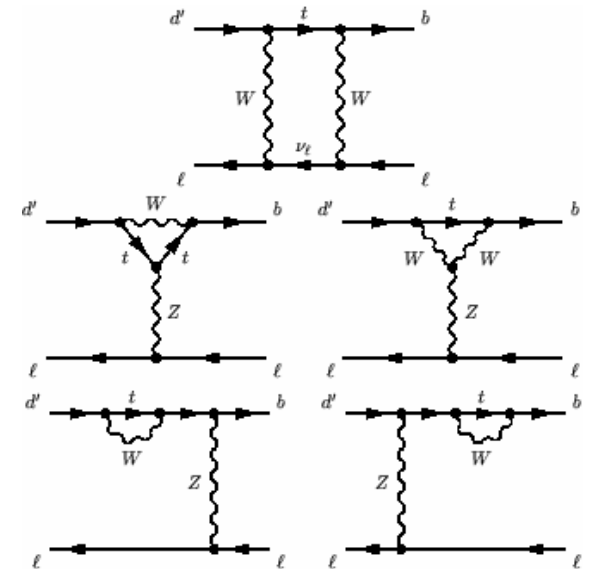
$$BR(B_s^0 \rightarrow \mu^+ \mu^-) < (3.42 \pm 0.54) \times 10^{-9}$$

- $B_d$  decay further suppressed:

$$\left| \frac{V_{td}}{V_{ts}} \right| = (4.0 \pm 0.8) \times 10^{-2}$$

- Observation of a significantly larger BR would indicate physics beyond the Standard Model

- ◆ Minimal Supersymmetric Standard Model
- ◆ Type-II 2-Higgs-doublet model
- ◆ Minimal supergravity models





# Rare Decays: $B_{d,s} \rightarrow \mu^+ \mu^-$



- Background sources include

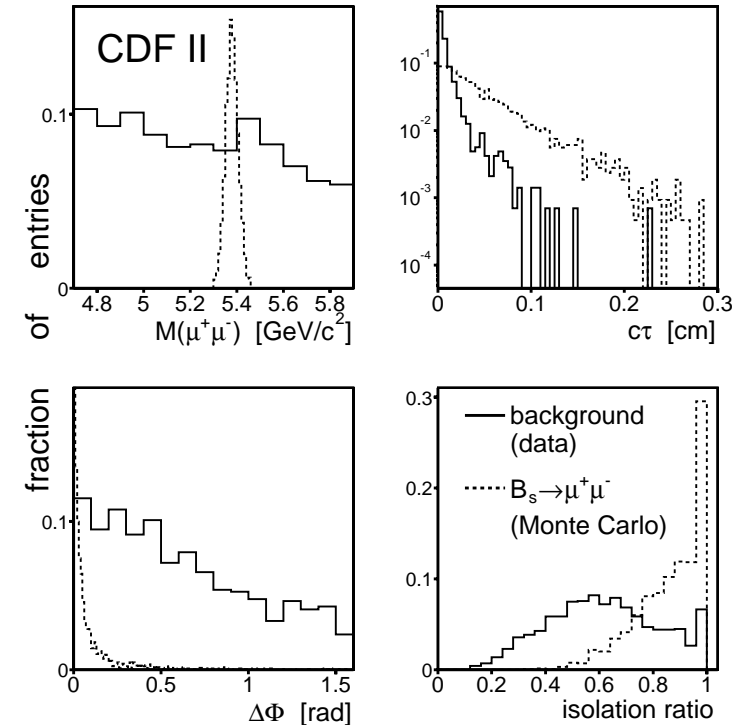
- ◆ Fakes
- ◆  $q\bar{q} \rightarrow \mu^+ \mu^-$
- ◆ Sequential semi-leptonic  $b \rightarrow c$  decay
- ◆ Double semileptonic decay  $b \rightarrow \mu^- X, \bar{b} \rightarrow \mu^+ X'$

- CDF published results using 171 pb<sup>-1</sup>

- ◆ One background event expected in each mass window; one event with mass consistent with both mass windows survived
- ◆  $BR(B_s^0 \rightarrow \mu^+ \mu^-) < 7.5 \times 10^{-7}$  at 95% C.L.
- ◆  $BR(B_d^0 \rightarrow \mu^+ \mu^-) < 1.9 \times 10^{-7}$  at 95% C.L.

- DØ used 240 pb<sup>-1</sup>

- ◆ 4 events observed in signal region consistent with  $3.7 \pm 1.1$  background events
- ◆  $BR(B_s^0 \rightarrow \mu^+ \mu^-) \leq 5.0 \times 10^{-7}$  at 95% C.L.





# Summary



- Both CDF and DØ are operating well
- Each has unique features important for successful B physics analyses
- Too many results to present in a 25 minute talk
- B Physics program at the Tevatron is broad and varied and complementary to that of the B factories
- More exciting results to come!